Switchgrass and Big Bluestem Hay, Biomass, and Seed Yield Response to Fire and Glyphosate Treatment

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ABSTRACT

Timing of spring fire and glyphosate [*N*-(phosphonomethyl)glycine] treatments is critical to control weeds without compromising production of warm-season grasses. To determine the forage and seed yield response we burned or applied glyphosate to switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman) in mid-April, early May, and late May in 1998 and 1999 at Rock Springs, PA. Compared with fire in mid-April or early May, a late May burn in 1998 reduced July dry matter yields (simulating a hay harvest) by 40 to 48% but did not affect dry matter yields in September (simulating a biomass feedstock harvest) of either grass. In switchgrass, glyphosate applied in late May reduced July yields by 70% and September yields by 30%. In bluestem, late May application of glyphosate reduced July yields by 90% and September yields by 40%. In both grasses, fire in late May reduced yields less than a late May application of glyphosate. Late May glyphosate treatments reduced seed yield compared with the mid-April date. We conclude that in central Pennsylvania switchgrass or bluestem can be burned through the first week of May (10–15 cm growth) with little effect on hay or biomass yield. Glyphosate should be applied (i) before mid- to late April (just before green-up) if switchgrass or big bluestem is to be harvested as hay in July or for seed in September, or (ii) by the first week of May if the cumulative growth is to be harvested once in autumn.

PERENNIAL WARM-SEASON GRASSES, such as switchgrass and big bluestem, have multiple uses including soil conservation, wildlife habitat, and livestock forage in the northeastern USA (Clubine, 1986). In the future, switchgrass may also be useful as a biofuels crop (Sanderson et al., 2004). Cool-season weeds often invade warm-season grasses during early spring before the warm-season grasses are competitive. Options for early season weed control on dormant warm-season grass sods in the northeastern USA include fire and herbicides.

Fire in spring has been used to control cool-season weeds in tallgrass prairie of the Great Plains (Towne and Kemp, 2003). Developmental stages at the time of burning and morphological characteristics of the plant are key factors in determining how fire affects plants (Steuter and McPherson, 1995). Burning when the cool-season weeds are actively growing and the growing points exposed is most effective for their control. Plant morphology that maintains a pool of active meristems just below the soil surface, such as crown buds or rhizomes, aids plant tolerance to fire.

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Fire may not be an option for managing warm-season grasses in densely populated areas of the northeastern USA where rural and urban land uses intermingle. Thus, herbicides may be the only tool available to control weeds. Broadleaf weeds in perennial warm-season grasses can be controlled with selective herbicides such as 2,4-D [(2,4-dichlorophenoxy)acetic acid] and dicamba (3,6-dichloro-2-methoxybenzoic acid) (Mitchell and Britton, 2000). Imazapic (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid) can be used postemergence to control many weeds in big bluestem; however, imazapic severely injures switchgrass. Glyphosate, a nonselective postemergence herbicide, can be used to control invasive cool-season grasses in stands of dormant perennial warm-season grasses (Waller and Schmidt, 1983); however, application timing will influence crop safety.

Timing of spring fire and herbicide treatments is critical to both control weeds and prevent damage to the warm-season grasses. Sometimes weeds may not have reached the proper developmental stage for effective herbicide control before the warm-season grass has greened up in the spring. Thus, waiting to apply a nonselective herbicide, such as glyphosate, or burning too late may damage the warm-season grass and reduce production. Applying herbicide or fire too early may miss the initial flush or allow a second flush of weeds to emerge and compete with the warm-season grasses. Moreover, use of fire too early may reduce the availability of soil moisture for warm-season grass growth by exposing the soil to sunlight and encouraging evaporation (Mitchell and Britton, 2000).

Generally, the use of fire in late April or early May has increased production, reproductive stem density, and seed yields of some warm-season grasses in native tallgrass prairie in the central Great Plains (Masters et al., 1992, 1993). Because fire may not be an acceptable option in densely populated areas of the northeast, glyphosate may be the only option for controlling some invasive cool-season grasses. However, data are lacking to indicate how switchgrass and big bluestem respond to glyphosate applied at various spring dates. The purpose of this study was to determine how fire or glyphosate application at various times in the spring affected forage and seed yields in switchgrass and big bluestem.

MATERIALS AND METHODS

The field experiment was conducted in 1998 and 1999 at the Russell E. Larson Agricultural Research Center near Rock Springs, PA. Soil at the site is a Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs). Soil tests indicated no need for lime, P, or K.

Established plantings of three cultivars (Pathfinder, Trailblazer, and NJ-50) of switchgrass and two cultivars (Pawnee and Niagara) of big bluestem were used for the experiment. The grasses were established in 1979 and had been managed at a low level (either not harvested or only one harvest per year, no fertilizer input) for the 10 yr ending in 1996. The plots were not harvested in 1997. Visual observations of the plots indicated good stands of both grasses. Weather data were collected from a meteorological site within 1 km (Table 1).

Separate experiments were conducted for switchgrass and big bluestem. Each experiment was a randomized complete block design with three blocks (one for each of three cultivars) for switchgrass and two blocks (one for each of two cultivars) for big bluestem. Each block (cultivar) contained two replicate plots (5.2 by 15.2 m) of all treatments. Thus, each treatment was replicated six times for switchgrass and four times for big bluestem. Seven treatments were compared during 1998 and 1999: three dates of fire or herbicide application and a control that was neither burned nor treated with glyphosate. In 1998 the dates of burning were 15 April, 6 May, and 22 May and the glyphosate was applied on 21 April, 6 May, and 25 May. In 1999 the dates of burning were 28 April, 6 May, and 14 May and the glyphosate was applied on 28 April, 6 May, and 18 May. Glyphosate was applied at 1.12 kg ha^{-1} with an ATV-mounted boom sprayer in 190 L ha^{-1} water at 207 kPa. A nonionic surfactant was included at 0.25% (v/v) with the glyphosate. The treatments were repeated on a different set of plots in an adjacent area in 1999. The plots used in 1999 were not cut or burned in 1998. The variations in treatment dates resulted from wind or rain delays. At the April treatment date switchgrass and big bluestem were just greening up and had about 2 to 5 cm of visible growth. Both grasses were 10- to 15-cm tall and had about two fully expanded leaves at the early May treatment date. At the late May treatment date both grasses were 25 to 30 cm tall and had three to four fully expanded leaves but had not yet elongated internodes. Weed control was not evaluated and all plots including the control plots were relatively weed-free.

In early April of each year, standing residue was clipped to a 10-cm stubble and removed from the plots designated for herbicide treatment. Standing residue was left in place on the control plots and in the plots designated for the fire treatments. Standing residue in plots averaged 7000 kg dry matter ha^{-1} for switchgrass and 5500 kg ha^{-1} for big bluestem in April 1998. We did not measure standing residue in 1999.

Grass yield was determined in July and September of each year by hand-harvesting four 0.6- by 0.6-m quadrats from separate areas of each plot. The July harvest simulated the use for hay, whereas the September harvest simulated the use for biomass feedstock (cumulative growth from April or May–September). Each quadrat was cut to a 15-cm stubble and bagged separately and dried at 55°C for 48 h to determine dry matter yield. In September of each year, the number of inflorescences in each quadrat was counted and the inflorescences removed and threshed by hand. The glumes were removed from switchgrass and the glumes, lemmas, and paleas were removed from bluestem by hand rubbing and in an air-column seed blower. The seed unit in switchgrass consists of the fertile floret (i.e., the caryposis), whereas in big bluestem the seed unit consists of "the entire fertile sessile spikelet that includes a rachis joint and the pedicel that supported the pedicellate spikelet" (Moser and Vogel, 1995). Thus, in our study we cleaned to the seed unit in switchgrass and to the caryopsis in big bluestem. We converted the caryopsis yield of big bluestem to seed-unit yields by the conversion factor of Harlan and Ahring (1960; 1.83 times the caryopsis yield). Seeds were air-dried (22°C) and yield was calculated along with 100-seed or caryposis mass.

Data were analyzed separately for each grass species, year, and harvest within years. The GLM procedure in the Statistical Analysis System (Freund and Littell, 1981) was used to conduct the analyses. Planned treatment comparisons (single degree of freedom contrasts) included (i) control vs. the average of fire and glyphosate treatments, (ii) mid-April vs. late May fire, (iii) mid-April vs. late May glyphosate, and (iv) late May fire vs. late May glyphosate. Statistical significance was declared at the $P < 0.05$ level.

Table 1. Air temperature and precipitation at Rock Springs, PA, during 1998 and 1999.

Month	Avg. monthly air temp.			Precipitation		
	1998	1999	30-yr mean	1998	1999	30-yr mean
	°C			m		
January	1.9	−0.5	−4.3	99	135	61
February	1.5	1.0	−2.9	108	32	66
March	4.1	3.0	2.5	85	92	79
April	10.7	9.0	8.7	190	94	74
May	17.6	15.1	14.8	92	37	92
June	19.2	19.2	19.5	91	104	102
July	21.4	22.9	21.8	81	61	92
August	21.7	19.4	20.9	84	146	81
September	19.0	16.9	16.8	35	133	82
October	11.7	12.1	10.6	69	36	72
November	5.9	6.0	5.0	23	81	84
December	3.4	1.0	−1.3	14	53	66

RESULTS AND DISCUSSION

Hay and Biomass Yields

In 1998, switchgrass hay yields in July were reduced by both fire and glyphosate treatments in May (Table 2). A late May fire treatment reduced switchgrass hay yields by 48% compared with fire in mid-April. A late May application of glyphosate, however, reduced switchgrass hay yields by 74% compared with the mid-April applica-

Table 2. Yields of switchgrass treated with fire or glyphosate during 1998 and 1999 at Rock Springs, PA. The July harvest simulated a hay harvest at the boot stage and the September harvest (April or May–September cumulative growth) simulated a biomass feedstock harvest.

Treatment	1998		1999	
	July	September	July	September
	dry matter, kg ha^{-1}			
Fire				
Mid-April†	6200	10 740	2950	6330
Early May	4520	10 870	2520	6290
Late May	3250	8 390	2740	5510
Glyphosate				
Mid-April‡	6040	10 890	3030	6680
Early May	4330	10 810	3330	5890
Late May	1540	7 650	860	5020
Control	4720	10 460	2050	3680
Standard error	440	1 040	320	560
Contrasts				
Control vs. avg. of other treatments	NS	NS	NS	**
Mid-April vs. late May fire	**	NS	NS	NS
Mid-April vs. late May glyphosate	**	**	**	*
Late May fire vs. late May glyphosate	**	NS	**	NS

* Significant at the 0.05 probability level. NS, not significant.
** Significant at the 0.01 probability level.
† Fire dates in 1998 and 1999 were 15 and 28 April, 6 May, 22 and 14 May.
‡ Glyphosate application dates in 1998 and 1999 were 21 and 28 April, 6 May, 25 and 18 May.

Table 3. Yields of big bluestem treated with fire or glyphosate during 1998 and 1999 at Rock Springs, PA. The July harvest simulated a hay harvest at the boot stage and the September harvest (April or May–September cumulative growth) simulated a biomass feedstock harvest.

Treatment	1998 July	1998 September	1999 July	1999 September
	dry matter, kg ha^{-1}			
Fire				
Mid-April†	4920	7680	2560	3360
Early May	4860	6540	2550	4250
Late May	2960	6820	2510	6020
Glyphosate				
Mid-April‡	5010	6920	3570	4280
Early May	3160	6750	2660	4160
Late May	810	3560	330	2510
Control	5510	6550	2420	3490
Standard error	470	570	580	610
Contrasts†				
Control vs. avg. of other treatments	**	NS	NS	NS
Mid-April vs. late May fire	**	NS	NS	**
Mid-April vs. late May glyphosate	**	**	**	**
Late May fire vs. late May glyphosate	**	**	**	**

** Significant at the 0.01 probability level. NS, not significant.
† Fire dates in 1998 and 1999 were 15 and 28 April, 6 May, 22 and 14 May.
‡ Glyphosate application dates in 1998 and 1999 were 21 and 28 April, 6 May, 25 and 18 May.

tion date. September biomass yield of switchgrass was not affected by the date of fire treatment; however, glyphosate applied in late May reduced switchgrass biomass yields by 30% compared with a mid-April treatment. A similar pattern of responses to fire and glyphosate treatment was observed in big bluestem (Table 3). Use of fire in late May reduced hay yields in big bluestem by 40% compared with fire in mid-April, whereas late May glyphosate application reduced hay yields by 84% and September biomass yields by 48% compared with the mid-April treatment.

Switchgrass hay and biomass yields were not affected by the date of fire in 1999 (Table 2). A late May glyphosate application, however, reduced hay yields by 72% and September biomass yields by 25% compared with the mid-April treatment. In 1999, big bluestem hay yields were not affected by fire, whereas the late May glyphosate treatment reduced hay yields by 91% and reduced September biomass yields by 41% compared with the mid-April treatment (Table 3). September biomass yields of big bluestem, however, increased by 79% with fire in late May. We do not know the reason for this anomalous response in bluestem yield. Others have reported that burning later in spring conserves soil moisture perhaps benefiting yield (Mitchell and Britton, 2000). We did not see a yield increase with fire treatments in switchgrass (Table 2), which may indicate that soil moisture was not the explanation for the bluestem yield response. Differences between years in hay and biomass yields probably were caused by differences in rainfall amounts and distribution (Table 1). Spring rainfall was plentiful in 1998 and near the long-term average for the summer. March and April rainfall were above average in 1999; however, rainfall in May and July was much below normal.

Delaying harvest until September may have allowed the grasses to recover from the herbicide injury in the spring. Additional regrowth from crown buds or rhizomes of both grasses may have contributed to the avoidance of long-term injury from glyphosate or fire. Thus, glyphosate should not be applied to switchgrass and big bluestem after mid- to late April (just before green-up) if the stand is to be harvested for hay at the boot stage (July in central Pennsylvania) and high yields are desired. A slightly later application (the first week of May) could be tolerated if the grasses were managed for a single fall harvest.

Fire combined with N fertilizer greatly increased the production of warm-season grasses on native tall grass prairie in Nebraska (Masters et al., 1992, 1993). Mitchell et al. (1994) reported that fire in late April increased big bluestem forage yield on native tallgrass prairie in Nebraska by 18 to 36% compared with fire on 31 March and increased yields by 52% compared with no fire. Reasons for the increased production included removal of standing dead material and litter, which improved the light environment for the emerging grass shoots and warmed the soil. In contrast, burning relatively young (5-yr-old) monocultures of switchgrass or big bluestem reduced forage yields compared with unburned plots during 3 yr in Nebraska (Cuomo et al., 1996). In that study, delaying fire from mid-March to mid-May progressively decreased yields of both grasses. Fire in mid-May reduced yields by half compared with unburned plots each year. Cuomo et al. (1996) reasoned that reduced amounts of litter and standing dead in their study accounted for the different response compared with that of Mitchell et al. (1994). Use of fire in late May sometimes reduced hay and biomass yields of switchgrass and big bluestem in our study, which agrees with the yield results of Cuomo et al. (1996).

Based on our results, if fire is included in the management of switchgrass and big bluestem, we recommend that burning should take place by the first week of May (i.e., no more than 10 to 15 cm of new growth) at the latest if stands are managed for hay production (harvest at boot stage). If switchgrass and big bluestem are managed for a single autumn harvest for biomass feedstock, fire in mid- to late May (less than 25 cm of new growth) would be acceptable in terms of biomass yields. We did not address the frequency of fire in this study, but other research indicates that burning every year can be harmful to warm-season grasses (Cuomo et al., 1996).

Seed Yields

Seed yields of switchgrass were not different among treatments in 1998 and averaged 480 kg ha^{-1} (Table 4). Both fire and glyphosate treatments increased switchgrass seed yields in 1999 compared with the control treatment. The late May glyphosate treatment reduced seed yields compared with the mid-April application. Seed yield of big bluestem was not affected by the date of fire in 1998; however, glyphosate applied in mid- or late May reduced seed yields compared with the mid-April treatment date. In 1999, seed yield of big bluestem was greater in the fire and glyphosate treatments compared with the control. Use of fire in mid-May in Nebraska increased seed yields of big bluestem in native prairie (Masters et al., 1993).

Switchgrass seed yield averaged 320 kg ha^{-1} across all treatments and years. Some commercial seed fields in the Northeast average 224 kg ha^{-1} of pure live seed with 112 kg N ha^{-1} (Andy Ernst, Ernst Conservation Seeds, Meadville, PA, personal communication, 2004). Switchgrass seed yields of up to 900 kg ha^{-1} have been reported in Iowa (Kassel et al., 1985); 80 to 700 kg ha^{-1} in Missouri (Brejda et al., 1994); and 2 to 390 kg ha^{-1} in Kansas (Cornelius, 1950). Big bluestem seed yields averaged 22 kg ha^{-1} in our study. Commercial big bluestem fields in the Northeast average about 112 kg ha^{-1} of pure live seed with 112 kg N ha^{-1} (Andy Ernst, Ernst Conservation Seeds, Meadville, PA, personal communication, 2004). Masters et al. (1993) reported big bluestem yields of 4 to 21 kg pure live seed ha^{-1} in native prairie.

We looked at differences in the number of inflorescences m^{-2} and 100-seed mass to explain seed yield differences. The density of inflorescences did not differ among treatments in either grass in 1998 (average of 148 inflorescences m^{-2} for switchgrass and 138 m^{-2} for big bluestem) and in switchgrass in 1998 and 1999 (average of 106 inflorescences m^{-2}; data not shown). In 1999, the density of big bluestem inflorescences was greater in the treated plots (average of 96 inflorescences m^{-2}) than in the control (48 inflorescences m^{-2}). Other research also has shown that inflorescence density increased with the use of fire in tallgrass prairie (Benning and Bragg, 1993; Masters et al., 1993).

Treatments did not differ in 100-seed mass in 1998 for switchgrass and 1999 for big bluestem (data not shown). In 1998, the late May application of glyphosate significantly reduced caryopsis mass in big bluestem compared with the mid-April application date (177 mg 100 caryopses^{-1} vs. 124 mg 100 caryopses^{-1}). In 1999, the 100-seed mass of the switchgrass control was significantly less than that for the average of all fire and glyphosate treatments (76 mg 100 seed^{-1} vs. 103 mg 100 seed^{-1}). The 100-seed mass of switchgrass in our experiment was in the ranges reported by Boe (2003; 101–175 mg 100 seed^{-1}) and Brejda et al. (1994; 73–149 mg 100 seed^{-1}). Caryopsis mass of bluestem was in the range reported by Springer (1991; 142–175 mg 100 caryopses^{-1}).

The lack of significance in 100-seed mass and inflorescence density in 1998 is consistent with the similarity in seed yields among treatments (Table 3). In 1998, the reduced big bluestem seed yield with late glyphosate application appeared related to differences in the density of inflorescences and 100-caryopsis mass. The increased seed yields in big bluestem in 1999 appeared to be related to a trend of increased caryopsis mass and perhaps inflorescence density. We did not measure the number of seeds produced per inflorescence, which could also have accounted for some differences in yields. Seed yield differences between years probably resulted from differences in rainfall. Rainfall was below the long-term average and temperature was above average in July 1999, which may have affected pollination and seed set.

Table 4. Seed yields of switchgrass and big bluestem treated with fire or glyphosate during 1998 and 1999 at Rock Springs, PA.

Treatment	Switchgrass 1998	Switchgrass 1999	Big bluestem 1998	Big bluestem 1999
	seed, kg ha^{-1}			
Fire				
Mid-April†	450	220	16	15
Early May	560	300	19	68
Late May	420	200	17	39
Glyphosate				
Mid-April‡	470	170	29	26
Early May	530	120	12	23
Late May	380	85	4	24
Control	550	60	12	6
Standard error	72	22	6	9
Contrasts				
Control vs. avg. of other treatments	NS	**	NS	**
Mid-April vs. late May fire	NS	NS	NS	NS
Mid-April vs. late May glyphosate	NS	**	**	NS
Late May fire vs. late May glyphosate	NS	**	**	NS

** Significant at the 0.01 probability level. NS, not significant.
† Fire dates in 1998 and 1999 were 15 and 28 April, 6 May, 22 and 14 May.
‡ Glyphosate application dates in 1998 and 1999 were 21 and 28 April, 6 May, 25 and 18 May.

Although weed control was not a component of this study, previous research indicated that cool-season weed control generally increases as glyphosate application is delayed in the spring (Mitchell and Britton, 2000). Both weed and warm-season grass stage of development should be assessed before glyphosate application. Cool-season weeds, such as quackgrass (*Elytrigia repens* L. Nevski) should have at least four leaves for effective control with glyphosate (Ivany, 1988; Rioux et al., 1974). In central Pennsylvania, effective quackgrass control was achieved when it was treated with glyphosate when at a 7.5- to 15-cm height on 22 or 25 April (Curran et al., 1994).

SUMMARY AND CONCLUSIONS

Generally, the timing of fire treatments had relatively small effects on hay or biomass yields of switchgrass and big bluestem. When hay or biomass yields were affected, the late May fire treatment did not reduce yields as much as a late May application of glyphosate. Timing of fire did not seem critical for seed production. Delaying glyphosate application into May frequently reduced hay, biomass, and seed yields of switchgrass and big bluestem. Thus, mid- to late April (just before grass green-up) seems to be the threshold date for glyphosate application to established switchgrass and big bluestem in climates similar to central Pennsylvania. Frequently, the herbicide effect on hay yields in July persisted into the autumn harvest; however, fire effects on yield were most evident in the summer harvest. Thus, fire or glyphosate application time may be more flexible for these grasses managed for a single late season harvest, such as for biomass energy feedstock production, than for a cut at the boot stage for hay. These recommendations could be adjusted earlier for areas farther south where warm-season grasses green-up earlier.

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